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(71) Applicant (*for all designated States except US*): SURFACE TECHNOLOGY SYSTEMS LIMITED [GB/GB]; Imperial Park, Newport, Gwent NP1 9UJ (GB).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): MCQUARRIE, Andrew, Duncan [GB/US]; 16066 Highland Drive, San Jose, CA 95127 (US).

(74) Agents: EASTWOOD, Simon, Christopher et al.; Wynne-Jones, Laine & James, 22 Rodney Road, Cheltenham, Gloucestershire GL50 1JJ (GB).

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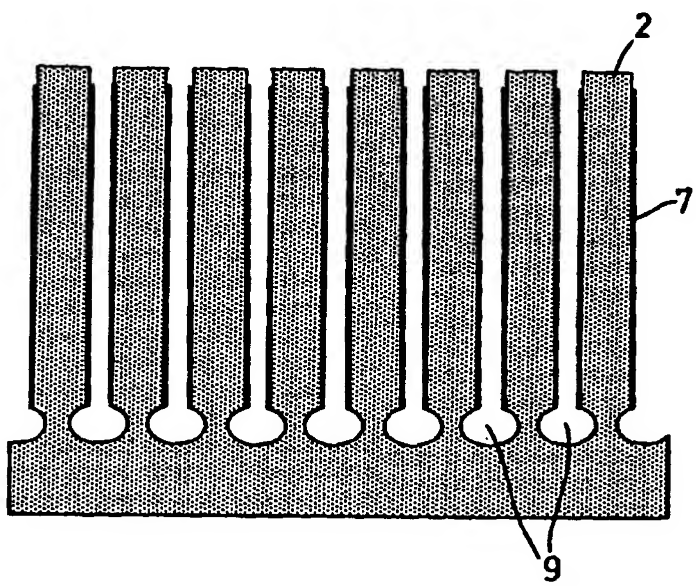
(54) Title: METHOD AND APPARATUS FOR MANUFACTURING A MICROMECHANICAL DEVICE



(57) Abstract

There is disclosed a method of manufacturing a micromechanical device. The method comprises the steps of: (a) etching a substrate (1), having a mask (2) thereon, through an opening in the mask to a desired depth to form a trench (6) having a side wall (4) and a base (5) in the substrate (1); (b) depositing a layer of a protecting substance (7) on the exposed surfaces of the substrate and mask; (c) selectively removing the protecting substance (7) from the base (5); and (d) etching the base (5) using a fluorine-containing etchant. Also disclosed is a micromechanical device formed by the method and an apparatus for manufacturing the micromechanical device.

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Method and Apparatus for Manufacturing a Micromechanical Device

The present invention relates to a method and apparatus for manufacturing a micromechanical device using a fluorine etchant source, for example xenon difluoride (XeF_2). Xenon difluoride is a dry isotropic gas phase etchant, which provides a gentle etch for silicon at low temperature. Xenon difluoride is usually supplied in the form of colourless crystals which sublime without decomposition. The sublimation pressure for XeF_2 is approximately 4 Torr.

A current method of manufacturing a micromechanical device uses the steps of anisotropic etching, mask removal, silicon oxide deposition, selective oxide etching, and isotropic etching of silicon with a SF_6 plasma and oxide strip. However, this method requires many steps which results in long cycle times and a high cost. Other methods etch down to a buried oxide layer of silicon dioxide and selectively stop the anisotropic silicon etch at that interface. The silicon oxide is then selectively removed by HF to release the silicon structures. However, this method requires the use of wafers having a buried oxide layer which are very costly as well as additional equipment for HF based etching. Furthermore, liquid HF etching itself has considerable potential for stiction issues.

According to a first aspect of the present invention, there is provided a method of manufacturing a micromechanical device comprising the steps of:

(a) etching a substrate, having a mask thereon, through an opening in the mask to a desired depth to form a trench having a side wall and a base in the substrate;

(b) depositing a layer of a protecting substance on the exposed surfaces of the substrate and mask;

(c) selectively removing the protecting substance from the base; and

(d) etching the base using a fluorine-containing etchant.

The fluorine-containing etchant may be a gas or vapour used to etch the substrate in the absence of a plasma.

Preferably, the fluorine-containing etchant is XeF_2. However, other vapours such as F_2 or ClF_3 (which will either etch or enhance the etch rate of silicon in the gas phase) as discussed in our co-pending British Patent Application No. 9904925.6 may be equally applied either as a replacement to XeF_2, or in the form of a mixture, for example with XeF_2. Thus, whilst the use of XeF_2 is discussed below in detail, other gases could be used.

Conveniently, the mask may be provided with a plurality of openings therein.

The method may further comprise the step of removing the mask and remaining protecting substance. This removal may be by means of a plasma. The substrate is preferably formed of silicon.

In a preferred embodiment, the mask is deposited by a photolithographic process.

The substrate is preferably etched by substantially anisotropic etching. The anisotropic etching may conveni-

ently be performed using the methods described in EP-A-0822582 and EP-A-0822584, the contents of which are incorporated herein by reference.

The use of XeF_2 in a method and apparatus for etching a workpiece are disclosed in British Patent Application No. 9709659.8, the contents of which are incorporated herein by reference.

The protecting substance may be of the form C_YF_X (where X and Y may be any suitable value) such as CF_x polymeric chains, where x may be 2. Thus, the protecting substance may be of the general formula $n(CF_2)$. One example may be cross-linked PTFE. The deposition may be performed by generating a plasma, for example an RF plasma, with an appropriate source gas, for example C_4F_8. In a preferred embodiment, a typical deposition thickness of the protecting substance is in the range of about 10 to 100 nm. Alternatively, the protecting substance may be of the form C_YH_X such as CH_X polymeric chains, where x may be 2. Thus, it may be of the general formula $n(CH_2)$. In this case the source gas may be CH_4, for example. Again X and Y may be any suitable value.

The protecting substance may be selectively removed from any or all of the surfaces other than the side wall and etching with the fluorine-containing etchant may take place on all resulting unprotected areas.

The protecting substance may selectively be removed by a plasma such as oxygen or (well known) mixtures with argon, helium, or nitrogen for example. The requirement for selec-

tive removal may be achieved by a suitable plasma process as known in the art.

The etching with the fluorine-containing etchant may be isotropic etching of the unprotected areas of the substrate.

According to a second aspect of the present invention, there is provided a device formed by the above method.

The device may be formed as a series of adjacent fingers separated by trenches. A fluorine-containing etchant, for example XeF_2, may be used to undercut such that the trenches are in communication.

According to a third aspect of the present invention, there is provided an apparatus for manufacturing a micromechanical device comprising:

(a) means for etching a substrate, having a mask thereon, to a desired depth;

(b) means for depositing a layer of a protecting substance on the exposed surfaces of the substrate and mask;

(c) means for selectively removing the protecting substance; and

(d) means for providing a fluorine-containing etchant for etching the unprotected areas.

The means for depositing the protecting substance may be means for generating a plasma. The means for selectively removing the protecting substance preferably includes means for providing a suitable plasma.

In a preferred embodiment, the apparatus may further comprise means for removing the mask and the remaining protecting substance and this means may be a plasma source,

preferably an oxygen plasma source.

Although the invention has been described above, it is to be understood that it includes any inventive combination of the features set out above or in the following description.

The invention may be performed in various ways and a specific embodiment will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a cross section of a silicon substrate having a pattern photoresist;

Figure 2 is a cross section view corresponding to that in Figure 1 in which the silicon has been etched;

Figure 3 shows a cross sectional view corresponding to Figures 1 and 2 in which a protecting layer has been deposited;

Figure 4 shows a corresponding cross sectional view in which the protecting layer has been selectively removed;

Figure 5 shows a corresponding cross section view showing a partial etch of the substrate;

Figure 6 shows a corresponding cross section view in which etching has been completed;

Figure 7 is a top view of inter-digitated silicon fingers formed by the method of the present invention;

Figure 8 is a cross sectional view of Figure 7 along the line A-A; and

Figure 9 shows a schematic view of an apparatus of the present invention.

Figure 1 shows a silicon substrate 1 on which is a patterned photoresist (mask) 2. The silicon substrate 1 is patterned by the use of photolithographic processes. Between the parts of the photoresist 2 are channels 3.

As shown in Figure 2, the silicon is then etched to a desired depth by anisotropic etching in a downward direction so that there is as little etching of the side walls of the formation as possible. The etching may be carried out by any suitable process. In this respect reference is made to EP-A-0822582 and EP-A-0822584. The etching leads to formation of side walls 4 and bases 5. The series of side walls 4 and bases 5 together form trenches 6.

As shown in Figure 3, a layer of a protecting substance is deposited on the exposed surfaces to a thickness of about 100 nm. The deposited layer is shown at 7. This layer is deposited in the process chamber by generating a RF plasma with the source gas being C_4F_8 and provides a layer of C_YF_X as mentioned above. One example is thought to be a layer of cross-linked PTFE.

Turning to Figure 4, an argon/oxygen mixture selectively removes the C_YF_X (for example the cross-linked PTFE) from the horizontal surfaces shown by upper surfaces 8 and bases 5. The requirement may be achieved by using, for example, low pressure reactive ion etching or inductively coupled plasma technique as mentioned above.

It is then possible to etch the unprotected silicon areas on the bases 5. Figure 5 shows the result of a partial etch which leads to etches 9. In the present

invention, XeF_2 is used to isotropically etch the unprotected silicon areas leading to the etches 9.

Figure 6 shows the result of etching to completion by XeF_2 followed by an oxygen plasma to remove both the photoresist 2 and remaining deposited layer 7. This etching provides the completed etch indicated by 10.

The method described above provides a simple approach to releasing silicon microstructures after they have been formed by anisotropic etching. Thus, Figure 5, as described above shows a structure in which the release process is happening and Figure 6 shows a structure when released. The method may be carried out sequentially in the same process chamber as the anisotropic etch. Thus, all the steps may be carried out in the same process chamber.

In the sequence shown by Figures 1 to 6, an example structure of inter-digitated silicon fingers is produced. The method may be applied to either bulk or polysilicon based structures.

Figures 7 and 8 show the final form of the resulting silicon microstructure in which inter-digitated silicon fingers 10 are shown.

Whilst the microstructures resulting from the present invention have a number of applications, typical applications for such structures may be accelerometers and gyroscopes which are based upon capacitance sensing between the silicon fingers by means of anchoring one set of silicon fingers 10 and allowing the other set to move when force is applied, this movement being sensed by the change in

capacitance.

Figure 9 illustrates a reactor chamber 11 suitable for use in the present invention. Typically, a vacuum chamber 12 incorporates a support electrode 13 for receiving a substrate 14 and a further spaced electrode 15. The substrate 14 may be pressed against the support 13 by a clamp 16. The chamber 12 is surrounded by a coil 17 and fed by a RF source which is used to induce a plasma in the chamber 12 between electrodes 13 and 15. Alternatively a microwave power supply may be used to create the plasma. In both cases there is a need to create a plasma bias, which can be either RF or DC and can be connected to the support electrode 13 so as to influence the passage of ions from the plasma onto substrate 14. An example of such an adjustable bias means is indicated at 19. The chamber is provided with a gas inlet port 20 and an exhaust port 21.

Claims

1. A method of manufacturing a micromechanical device comprising the steps of:

(a) etching a substrate, having a mask thereon, through an opening in the mask to a desired depth to form a trench having a side wall and a base in the substrate;

(b) depositing a layer of a protecting substance on the exposed surfaces of the substrate and mask;

(c) selectively removing the protecting substance from the base; and

(d) etching the base using a fluorine-containing etchant.

2. A method according to claim 1, wherein the fluorine-containing etchant is a gas or vapour used to etch the substrate in the absence of a plasma.

3. A method according to claim 1 or 2, wherein the fluorine-containing etchant comprises XeF_2, F_2, ClF_3 or mixtures thereof.

4. A method according to claim 1 or 2, wherein the fluorine-containing etchant is XeF_2.

5. A method according to any preceding claim, further comprising the step of removing the mask and remaining protecting substance.

6. A method according to any preceding claim, wherein the protecting substance is a fluorocarbon polymer of the general formula C_YF_X.

7. A method according to claim 6, wherein the protecting substance is of the general formula $n(CF_2)$.

8. A method according to any one of claims 1 to 5, wherein

the protecting substance is of the form C_yH_x.

9. A method according to claim 8, wherein the protecting substance is of the general formula $n(CH_2)$.

10. A micromechanical device formed by the method of any preceding claim.

11. A micromechanical device according to claim 10, comprising a series of adjacent fingers separated by trenches.

12. A micromechanical device according to claim 11, wherein the trenches are in communication.

13. An apparatus for manufacturing a micromechanical device comprising:

(a) means for etching a substrate, having a mask thereon, to a desired depth;

(b) means for depositing a layer of a protecting substance on the exposed surfaces of the substrate and mask;

(c) means for selectively removing the protecting sub-stance; and

(d) means for providing a fluorine-containing etchant for etching the unprotected areas.

14. An apparatus according to claim 13, further comprising means for removing the mask and the remaining protecting substance.

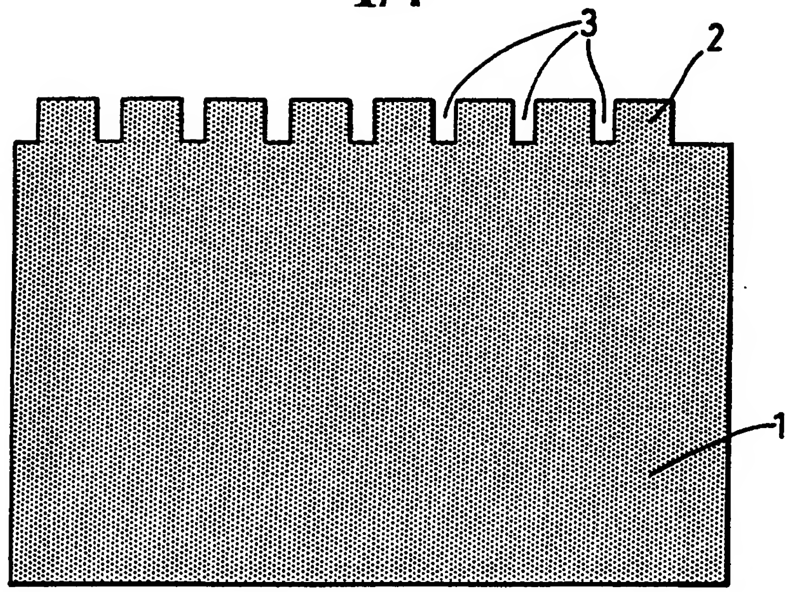

Fig. 1

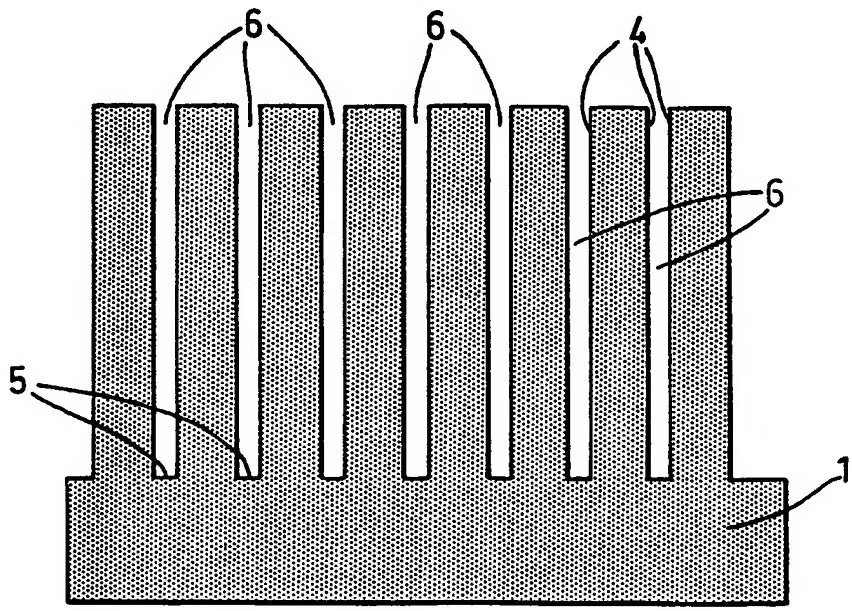

Fig. 2

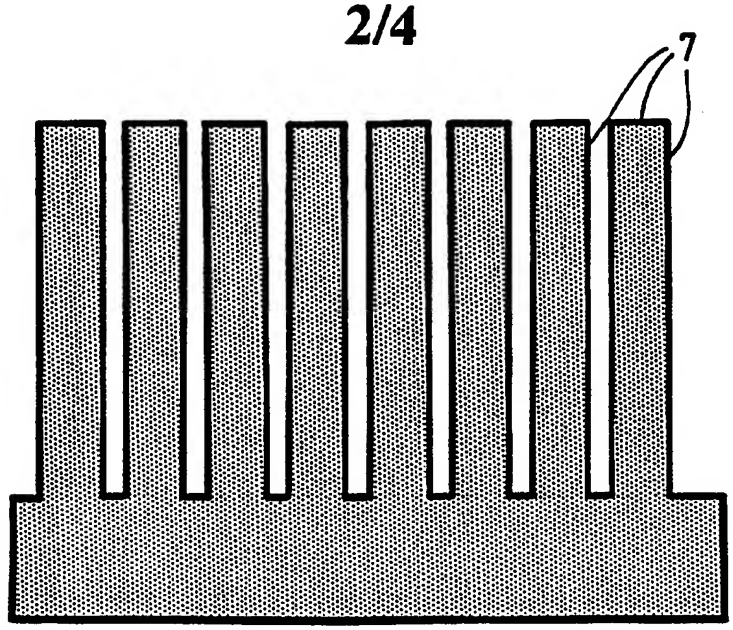

Fig. 3

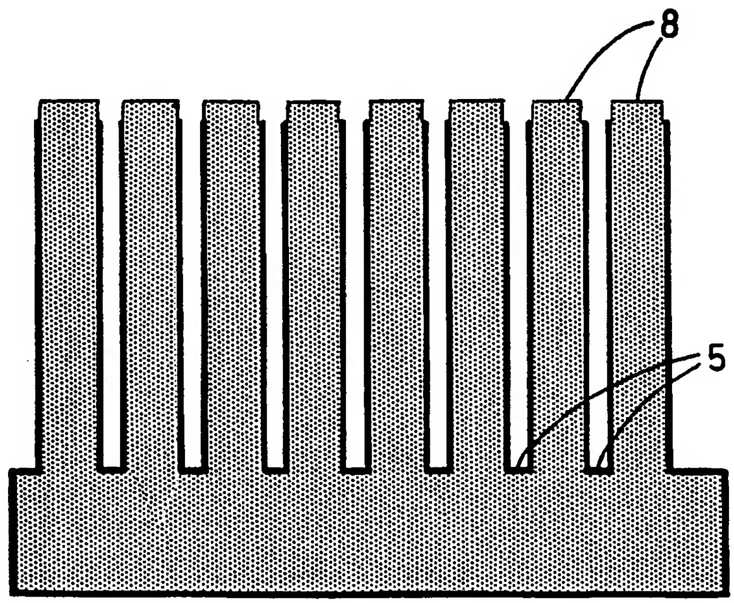

Fig. 4

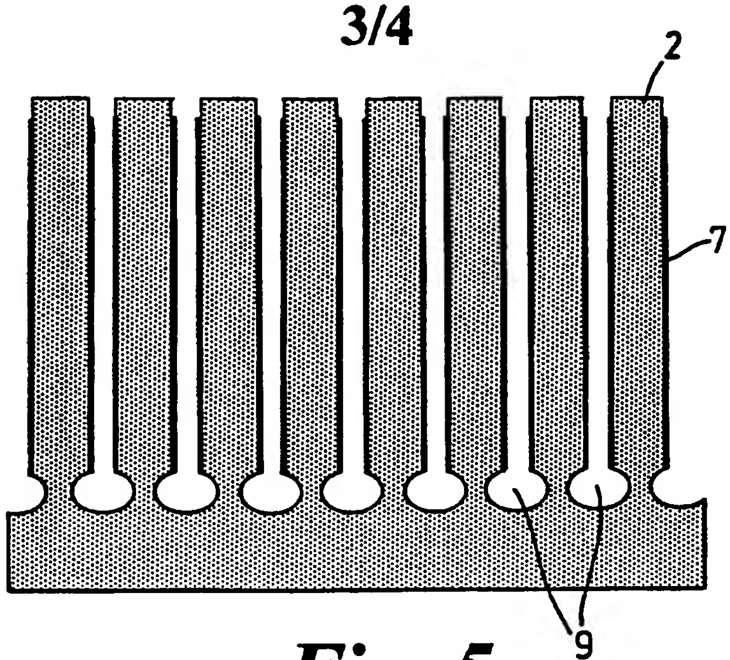

Fig. 5

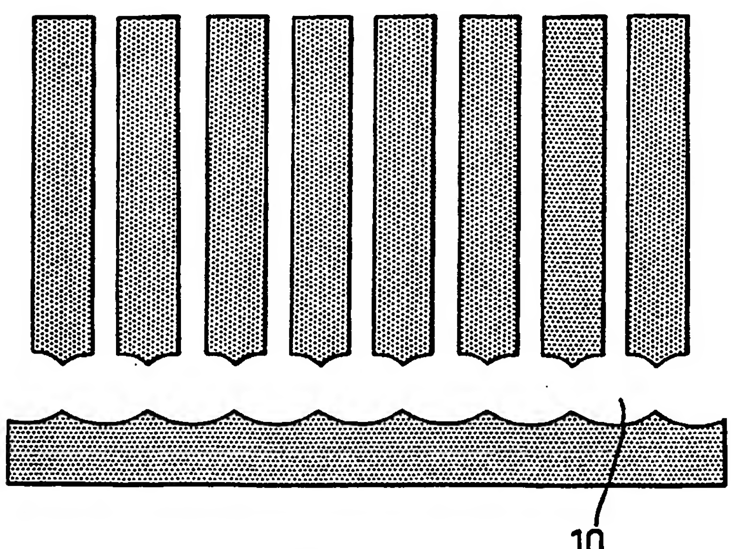

Fig. 6

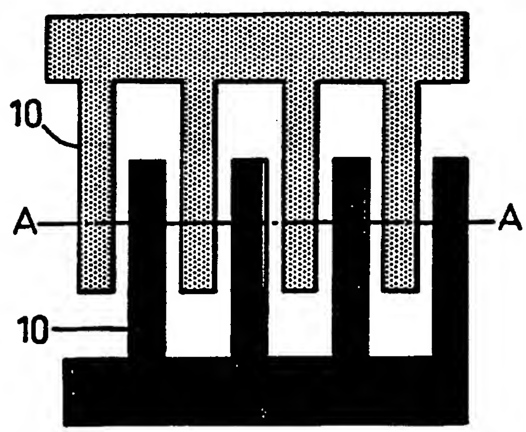

Fig. 7

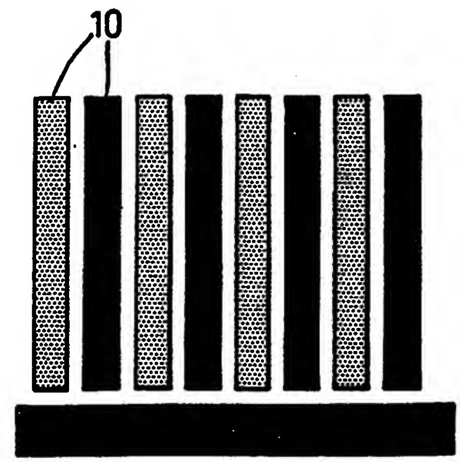

Fig. 8

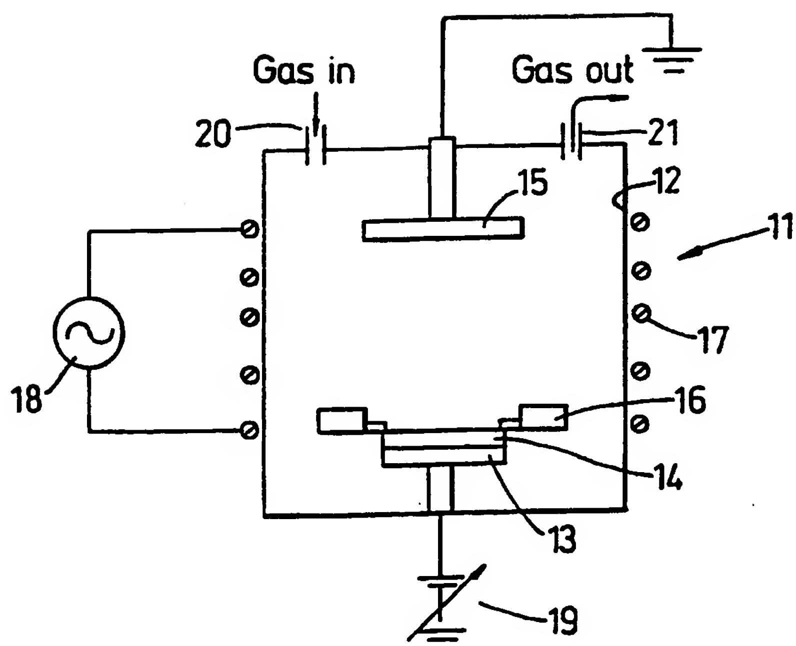

Fig. 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 99/00774

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01L21/3065

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01L B81C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	DE 42 41 045 C (BOSCH GMBH ROBERT) 26 May 1994 see the whole document ---	1,6,7, 10,13,14 2-4
X	EP 0 729 175 A (IBM) 28 August 1996 see column 1, line 1 - column 4, line 32; figures 3,4 ---	1,5,10, 11
X	EP 0 822 584 A (SURFACE TECH SYS LTD) 4 February 1998 cited in the application see page 2, line 3 - page 4, line 43 see page 8, line 21 - line 32; claims 1,5,8-10,18,19,21,22; figure 1 --- -/--	8,9,13, 14

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
7 June 1999	15/06/1999

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 316 979 A (MACDONALD NOEL C ET AL) 31 May 1994 see the whole document	1,10-12
Y	IBBOTSON D E ET AL: "Plasmaless dry etching of silicon with fluorine-containing compounds" JOURNAL OF APPLIED PHYSICS, NOV. 1984, USA, vol. 56, no. 10, pages 2939-2942, XP002910845 ISSN 0021-8979 see abstract see page 2939, column 1, paragraph 1 - column 2, paragraph 2; table 2	2-4

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 99/00774

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